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# Effect of Tidal Volume Size and Its Delivery Mode on Patient-Ventilator Dyssynchrony

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**Abstract**

**Rationale:** Although increasingly recommended, compliance with low tidal volume ventilation remains suboptimal. Dyssynchrony induced by low tidal volumes may be a reason for it.

**Objectives:** To determine the effect of tidal volume size, and of the ventilator mode used for its delivery (volume vs pressure control), on the magnitude of patient-ventilator dyssynchrony in patients with or at risk for acute respiratory distress syndrome (ARDS).

**Methods:** Nineteen mechanically ventilated patients underwent 6 consecutive ventilatory conditions. Three on volume assist-control (VC) mode, each with set tidal volume ($V_T$) of 6, 7.5 and 9 ml/kg, and 3 on adaptive pressure control (APC) mode with those same set $V_T$ and matching inspiratory times. Triggering, cycling and flow dyssynchronies were identified by inspection of airway flow and pressure tracings. A dyssynchrony index (DI) was calculated as the total number of dyssynchronies divided by the sum of ventilator cycles and ineffective triggering events, expressed as %. A severe DI was calculated including only double-triggering and severe flow dyssynchronies.

**Measurements and Main Results:** Under VC mode, the median (IQR) DI were 100 (22-100)% at set $V_T$ of 6 ml/kg, and 78 (7-100)% at 7.5 ml/kg, both higher than 25 (0-45)% at 9 ml/kg (p=0.02 and 0.01 respectively). Severe DI was higher at each reduction of $V_T$ size. Under APC mode, compared to VC, DI were lower at set $V_T$ of 6 and 7.5 ml/kg (p=0.004 for both). Changing from VC to APC resulted in an increase in exhaled $V_T \geq 1$ ml/kg PBW in a minority of patients.

**Conclusions:** Lower tidal volumes during volume control ventilation result in higher patient-ventilator dyssynchrony in most patients with or at risk for ARDS. The use of adaptive pressure-

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control mode is an option to reduce dyssynchrony, but requires careful monitoring to avoid larger than target delivered volumes.

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The use of low tidal volume during mechanical ventilation of patients with Acute Respiratory Distress Syndrome (ARDS) is recommended since a landmark study showed lower mortality in patients ventilated with a tidal volume of 6 ml/kg compared to 12 ml/kg of predicted body weight (PBW) (1). In addition, the use of low tidal volume is being proposed for ventilated patients without ARDS (2, 3) as evidence suggests it might prevent the development of the syndrome (4, 5). However, more than 10 years after that landmark study the clinical compliance with this ventilation strategy in ARDS patients, where the recommendation is strong, remains low (6, 7). The reasons for this low compliance are likely multiple, but we suspect that patient-ventilator dyssynchrony induced by setting a tidal volume at times insufficient to meet patient demands is an important one. Although dyssynchrony in this situation may be familiar to intensivists and different types of it have been reported (8-10), their prevalence and relationship with tidal volume size have not been well studied (11).

Besides this potential influence of tidal volume size, the ventilatory mode used can affect patient-ventilator synchrony (12). The commonly used flow-limited volume control mode may often not meet those high inspiratory demands of patients with or at risk for ARDS and predispose to dyssynchrony during volume delivery (9). Pressure-regulated modes of ventilation, by adjusting inspiratory flow to patient demand, can improve work of breathing and synchrony compared to volume control mode (13-16).

As the use of low tidal volume ventilation is increasingly recommended, it is important to further study dyssynchrony as a potential side effect and possible options to minimize it. The aims of this study were to determine the effect of tidal volume size, and of the ventilator mode

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(volume vs pressure control) used for its delivery, on the magnitude of patient-ventilator dyssynchrony in patients with or at risk for ARDS.

## Materials and Methods

### Patients

Nineteen non-consecutive patients of the medical critical care service undergoing invasive mechanical ventilation were enrolled in the study. Inclusion criteria were: mechanical ventilation for less than 72 hours, expectation to continue it for at least 48 hours, ventilation with volume or pressure assist-control mode and a diagnosis of ARDS by Berlin definition criteria (17) or the presence of a risk factor for ARDS without meeting all criteria for the syndrome.

Exclusion criteria were: age < 18 years, pregnancy, known or suspected severe chronic obstructive pulmonary disease, acute asthma exacerbation, known or suspected increased intracranial pressure, severe agitation in spite of sedatives prescribed, hemodynamic instability and pharmacologic or pathologic paralysis of respiratory muscles. All patients were ventilated with a Puritan Bennett 840 ventilator (Medtronic, Minneapolis, MN). The study was approved by the Institutional Review Board and written informed consent was obtained from each patient's next of kin.

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**Measurements and Data Collection**

Selected clinical data were collected from the medical record on the day of study procedures. Level of sedation was assessed using the Richmond Agitation-Sedation Scale (RASS) (18) just prior to initiating the ventilation protocol. Height was measured with a measuring tape as the distance from heel to crown with the patient in the supine horizontal position. Predicted Body Weight (PBW) was calculated with the formulas used in the low vs high tidal volume ARDS network trial (1). All patients were studied in the semi-recumbent position. Mechanical breathing variables were measured using the RSS100-HR Research Pneumotach System (Hans Rudolph Inc., Kansas City, MO). Its pneumotachograph, placed between the endo-tracheal tube and the Y-piece of the ventilator tubing, measured airway flow (by differential pressure) and pressure at a sample rate of 50 Hz. These measurements and the derived breathing variables calculated by the system were stored in a personal computer for later analysis.. One of the investigators present during the measurements marked episodes of coughing, gagging or attempts to talk on the recordings for later discard of these segments of data prior to analysis. Continuous recordings were taken during the 10 minutes duration of each ventilatory condition.

**Ventilation Protocol**

Patients were studied during 6 consecutive ventilatory conditions. A first sequence of 3 conditions was on volume assist-control (VC) mode, each with set tidal volume ($V_T$) of 6, 7.5 and 9 ml/kg PBW respectively. A second sequence of 3 conditions was on adaptive pressure control (APC) mode (Volume Control plus™, Puritan Bennett 840), each with those same sizes of set $V_T$.

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In this assist-control mode, each breath is a pressure regulated variable flow breath in which the level of inspiratory pressure is adjusted breath to breath via a volume feed-back according to a set target tidal volume. The order of $V_T$ size within each sequence was randomly determined for each patient before the start of the study.

During APC mode, the inspiratory times were set to match the inspiratory times measured and displayed breath-by-breath during the same set $V_T$ of the volume control sequence. During VC mode, the inspiratory flow was set to decreasing ramp pattern and maximum was 50 Lpm. During both modes, inspiratory sensitivity was set at flow-trigger of 3 Lpm while set respiratory rate, fraction of inspired oxygen ($F_IO_2$) and positive end-expiratory pressure (PEEP) remained at the clinically prescribed settings. Immediately before and throughout the measurements sedation was maintained at the target and with the medications clinically ordered.

**Analysis of Breathing Variables and Dyssynchrony**

The first 5 minutes of recordings for each condition were considered a period of stabilization and discarded. The last 5 minutes were used for analysis. Due to severe dyssynchrony associated with worsening hypoxemia the condition VC 6 ml/kg was terminated after 6 minutes in 2 patients, and the condition APC 6 ml/kg after 8 minutes in another patient. The last 5 minutes of these recordings were used for analysis. Breath-by-breath measured values of exhaled tidal volume ($V_Te$), respiratory frequency (f), peak inspiratory pressure (PIP), maximum inspiratory flow (peak $\dot{V}_I$) and inspiratory time ($T_I$) were averaged for this duration. Simultaneous pressure-time and flow-time plots were visually inspected by one of the

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investigators in consecutive segments of 20 second duration each. Ventilator cycles, individual dyssynchronies within them and ineffective triggering events were manually counted.

A ventilator cycle was defined as a machine or patient triggered positive pressure breath. Definitions of triggering dyssynchronies were adapted from the criteria used by Thille et. al (19) while those of cycling (20) and flow (21) dyssynchronies were derived from their description in the literature as follows. Ineffective triggering: decrease in expiratory flow along with a decrease ≥0.5 cm $H_2O$ in airway pressure after an expiratory time > half the inspiratory time has elapsed, not followed by an assisted ventilator cycle; auto-triggering: ventilator cycle delivered without prior decrease in airway pressure and occurring before the next mandatory cycle; double-triggering: 2 ventilator cycles separated by an expiratory time < half the inspiratory time; short ventilator cycling-off: decrease in expiratory flow immediately after the onset of expiration with simultaneous decrease in airway pressure not resulting in double-triggering; long ventilator cycling-off: sharp increase in airway pressure just before end inspiration; flow dyssynchrony: decrease of the pressure-time tracing during inspiration after its initial rise and followed by a subsequent increase; severe flow dyssynchrony: decrease of the pressure-time tracing during inspiration reaching below PEEP levels.

Representative examples of study patients with these types of dyssynchronies are shown in figure 1. For a ventilator cycle showing more than one type of dyssynchrony, only the predominant one at discretion of the investigator was counted. Double-triggered breaths were counted as one ventilator cycle. Auto-triggering events were not present in any patient. Although not all these mismatches in patient-ventilator interaction represent lack of simultaneous timing (dys-synchrony), this term is used to encompass all for simplicity.

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The magnitude of dyssynchrony was measured by calculating a dyssynchrony index and a severe dyssynchrony index. The dyssynchrony index was calculated as the number of all dyssynchrony events divided by the sum of ventilator cycles and ineffective triggering events, expressed as %. The severe dyssynchrony index was selected to reflect the dyssynchronies that we considered clearly detrimental to patients and most noticeable to clinicians. It was calculated as the sum of double-triggering and severe flow dyssynchrony events divided by the number of ventilator cycles, expressed as %.

**Statistical Analysis**

Analyzed variables were summarized with mean and standard deviation (SD) or median and inter-quartile range (IQR) according to their frequency distribution. Comparisons between the 3 conditions by set $V_T$ size on VC mode were carried using one way repeated measures analysis of variance or Friedman test followed by multiple comparisons using paired t-test or Wilcoxon signed rank test with Bonferroni corrections. Comparisons between VC and APC modes at the same set $V_T$ size were carried using paired t-test or Wilcoxon signed rank test. Resulting p values <0.05 were considered to indicate statistically significant differences. All statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC).

## Results

Patients' characteristics at the time of measurements are shown in Table 1.

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**Effect of set $V_T$ Size during VC Mode**

The breathing variables and the different types of dyssynchronies at each set $V_T$ are summarized and compared in Table 2. The 5 minute average total respiratory rates for each subject were higher than the ventilator set rates during all ventilatory conditions. As expected, during VC mode larger set $V_T$ conditions showed larger average exhaled $V_T$ and lower respiratory frequencies. Compared to a $V_T$ (ml/kg PBW) of 6, a $V_T$ of 7.5 resulted in a lower dyssynchrony index in 9 patients, while compared with a $V_T$ of 7.5, a $V_T$ of 9 resulted in lower dyssynchrony index in 14 patients. For these same comparisons, the severe dyssynchrony index was lower in 11 and 8 patients, respectively (Figure 2). Both dyssynchrony and severe dyssynchrony group indices were higher at lower sizes of set $V_T$ on VC mode (Figure 3).

**Effect of $V_T$ Delivery Mode**

A comparison of breathing variables and dyssynchronies between APC and VC modes is shown in Table 2. On APC mode, respiratory frequencies were lower except when $V_T$ was set at 9 ml/kg. The average exhaled $V_T$ was similar to that of VC when $V_T$ was set at 6 ml/kg, but larger when set at 7.5 and 9 ml/kg. The differences in measured $V_T$e between VC and APC are shown in Figure 4. Changing from VC to APC resulted in an increase ≥ 1 ml/kg PBW in 4, 3 and 2 patients for a set $V_T$ of 6, 7.5 and 9 ml/kg, respectively. Dyssynchrony and severe dyssynchrony indices were both lower under APC mode when set $V_T$ were 6 and 7.5 ml/kg (Figure 3).

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## Discussion

There are two main findings of this study that measured patient-ventilator dyssynchrony on patients with or at risk for ARDS at set tidal volumes of 6, 7.5 and 9 ml/kg PBW during volume and pressure control modes. First, that setting lower tidal volumes on volume control mode resulted in higher dyssynchrony for most patients. Second, that changing from volume control to an adaptive pressure control mode decreased dyssynchrony at those lower set tidal volumes, while it allowed an increase in average delivered tidal volume ≥ 1 ml/kg/PBW in only a minority.

Although dyssynchrony during low tidal volume ventilation of ARDS patients has been described (8, 9), its different types and relationship with tidal volume size, the key variable in this strategy, have received limited attention. Kallet et al (22) studied 10 patients with ARDS on volume control ventilation at different set tidal volumes and showed that patient work of breathing increased significantly at tidal volumes lower than 7 ml/kg. Although these investigators did not measure patient-ventilator dyssynchrony per se, this was a likely mechanism for or at least an associated phenomenon to the higher work of breathing they found at lower tidal volumes (11). In an observational study of 20 ARDS patients undergoing low tidal volume ventilation on volume control mode, Pohlman et al (10) found an inverse relationship between tidal volume and the frequency of a single type of dyssynchrony evaluated, double-triggering or “stacked-breaths”. Findings of these studies are in line with the current results.

Albeit not evaluating all different types of dyssynchrony, the use of pressure regulated ventilation to improve patient-ventilator interaction has been studied to a greater extent.

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Several studies in acute respiratory failure of various causes have shown that compared to volume control, pressure regulated ventilation can reduce work of breathing (13, 15), "breath-stacking" dyssynchrony (16) and possibly flow dyssynchrony (14). More recent studies however, indicated that when carefully matching tidal volume delivery parameters, particularly tidal volume size and inspiratory flow and/or time, pressure regulated ventilation per se does not decrease work of breathing in acute respiratory failure (13, 23, 24) and may result in lack of precise control of tidal volume size in some patients undergoing low tidal volume ventilation (25).

The current study found better synchrony with APC compared to VC when setting $V_T$ at 6 and 7.5 ml/kg. At these set tidal volumes, peak $\dot{V}_I$ did not differ between modes. While at set $V_T$ of 7.5 ml/kg $T_I$ was slightly longer (despite our attempt to match) and average actual delivered $V_T$ larger, these parameters were similar at 6 ml/kg. Of note, this latter lack of difference may be in part due to double-triggering during VC mode, leading to frequent larger than set actual tidal volumes at this set $V_T$ size. The improved synchrony found in the present study with APC mode at lower set tidal volumes can be due to a combination of better meeting flow demand other than its peak, allowing in some cases a longer inflation time and/or a larger $V_T$. As in a prior study (25), in few patients the magnitude of increase in actual delivered tidal volume from VC to APC was of potential concern for a lung protective strategy (6).

**Limitations**

Limitations of this study regarding the dyssynchrony method of measurement, its definition and ventilator specifics need to be considered. Measurements of esophageal pressure or even

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better diaphragmatic electromyography are more accurate methods to evaluate patient effort (26) and its synchrony with the ventilator. Although not a gold-standard, the method used in this study, analysis of pressure and flow waveforms, has high reliability for detecting dyssynchrony when compared to the inclusion of esophageal pressure in the measurement (19, 27) and has been an accepted one to study their prevalence and relationship with patients outcomes (19, 28). The periods of testing conditions and recording in this study were brief and not necessarily reflect patient-ventilator interactions of longer durations. However, this brevity minimizes the probability that changing levels of sedation influence dyssynchrony and act as confounder (16, 29).

Regarding its definition, there is no established standard to define and quantify overall dyssynchrony. Studies to date have defined dyssynchrony differently, used different ventilatory modes during their evaluation or focused on particular types of dyssynchrony (10, 14, 28). Furthermore, different dyssynchronies may differ in their mechanism for detrimental effect and in their relevance. We therefore decided to evaluate all common dyssynchronies and quantify them with an index including all and another one limited to two clearly detrimental and potentially most noticeable to clinicians. We defined each type of dyssynchrony following criteria or descriptions reported by others (19-21).

As in flow dyssynchrony its description using airway pressure contour may lack precision for consistent identification we limited our definition to a transient inspiratory decrease in the pressure tracing intending to detect those flow dyssynchronies clearly reflecting insufficient assistance during a breath (30). Regarding ventilator specifics, the peak (50 Lpm) and pattern of $\dot{V}_I$ used during VC mode and the set respiratory rates in relation to total rates in this study may

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not be uniform clinical practices. Variation in these settings may influence dyssynchrony. Similarly, differences in ventilators design regarding $V_T$ delivery and dual-control algorithms limit the generalization of the present findings to other ventilators.

Finally, the clinical implications of a higher magnitude of dyssynchrony in this setting are unclear. An association between dyssynchrony and worse clinical outcomes has been described in studies of ventilated patients in general (19, 28, 31).However, it is unknown whether that association applies when dyssynchrony develops in the context of low tidal volume ventilation or whether dyssynchrony modifies the proven beneficial effects of this ventilatory strategy. Regardless of any possible influence in outcome, the magnitude of dyssynchrony may be one reason to deter clinicians from a more widespread use of protective ventilation (32).

**Conclusions**

Lower tidal volumes during volume control ventilation resulted in more patient-ventilator dyssynchrony in most patients with or at risk for ARDS. Compared to volume-control, an adaptive pressure-control mode reduced dyssynchrony at these lower set tidal volumes with no or a small increase in delivered volume in a majority of patients. Dyssynchrony is a common side effect of low tidal volume ventilation. Individual tailoring of mode and parameters of tidal volume delivery is needed to minimize this effect and avoid higher than target lung volumes.

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## Figure Legends

**Figure 1.** Representative flow-time and airway pressure-time waveforms of patients with the different dyssynchronies assessed in the study. Arrows indicate events or cycles with dyssynchrony except for panels E and F where all cycles show dyssynchrony. A: ineffective triggering: transient decreases in expiratory flow and airway pressure indicate patient efforts to inspire that do not trigger a ventilator cycle; B: double-triggering: 2 ventilator cycles are triggered back to back by the inspiratory effort of the patient reflected by a lower airway pressure in the first cycles of each pair compared to the single triggered cycle; C- short ventilator cycling-off: transient decreases in expiratory flow and airway pressure immediately after the onset of expiration reflect persistent inspiratory efforts after mechanical inflation cycles-off; D: long ventilator cycling-off: sharp increases in airway pressure just before end inspiration reflect persistent positive pressure from the ventilator after cessation of patient inspiratory effort or even initiation of an expiratory effort; E: flow dyssynchrony: the transient decreases in airway pressure during mechanical inflation reflect patient inspiratory efforts clearly un-matched by the flow delivered by the ventilator; F: severe flow dyssynchrony: airway pressure during mechanical inflations reach levels lower than during expiration due to the same phenomenon as in E.

**Figure 2.** Individual dyssynchrony and severe dyssynchrony indices under volume control mode at different set tidal volumes ($V_T$).

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**Figure 3.** Median and IQR dyssynchrony and severe dyssynchrony indices under volume control (VC) and adaptive pressure control (APC) modes at different set tidal volumes ($V_T$). * indicates $p<0.05$ for comparisons between set $V_T$ sizes on VC mode and between VC and APC modes at the same set $V_T$ size.

**Figure 4.** Median and IQR differences in measured exhaled tidal volume ($V_Te$), expressed as ml/kg PBW, between adaptive pressure control (APC) and volume control (VC) mode at each set $V_T$ size.

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**Table 1.** Patients' characteristics at the time of measurements

| Subject | Age (y) | Gender (M/F) | ARDS (Y/N) | ARDS Risk Factor | RASS | $PaO_2/F_IO_2$ | PEEP (cm $H_2O$) | Set RR (1/min) |
|---|---|---|---|---|---|---|---|---|
| 1 | 34 | M | Y | Pneumonia | -4 | 123 | 7 | 12 |
| 2 | 46 | M | N | Shock - Massive transfusion | -5 | 178 | 5 | 15 |
| 3 | 80 | F | N | Aspiration | -3 | 230 | 5 | 12 |
| 4 | 57 | M | Y | Severe sepsis | -2 | 111 | 14 | 16 |
| 5 | 66 | M | N | Severe sepsis | 0 | 203 | 5 | 12 |
| 6 | 39 | F | N | Post-partum respiratory failure | -1 | 266 | 5 | 15 |
| 7 | 45 | M | N | Alveolar Hemorrhage | -2 | 79 | 10 | 12 |
| 8 | 47 | M | N | Pneumonia | -3 | 246 | 5 | 10 |
| 9 | 56 | M | Y | Pneumonia | -3 | 100 | 9 | 16 |
| 10 | 71 | F | Y | Pneumonia | -2 | 115 | 7 | 12 |
| 11 | 60 | F | N | Severe sepsis | 0 | 120 | 7 | 12 |
| 12 | 75 | M | N | Septic shock | -1 | 270 | 5 | 16 |
| 13 | 26 | M | Y | Aspiration | -3 | 142 | 10 | 12 |
| 14 | 64 | F | Y | Aspiration | -4 | 73 | 7 | 12 |
| 15 | 48 | F | N | Septic shock | -4 | 156 | 7.5 | 15 |
| 16 | 53 | M | Y | Aspiration | -4 | 83 | 8 | 12 |
| 17 | 75 | F | Y | Pneumonia | -2 | 86 | 10 | 15 |
| 18 | 49 | M | Y | Septic shock | 0 | 218 | 8 | 10 |
| 19 | 80 | F | Y | Pneumonia | -4 | 69 | 10 | 12 |

ARDS: Acute Respiratory Distress Syndrome; RASS: Richmond Agitation-Sedation Scale; PEEP: Positive End-Expiratory Pressure; RR: respiratory rate

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**Table 2.** Breathing variables and different types of dyssynchronies

| Mode | Volume Control | | | Adaptive Pressure Control | | |
|---|---|---|---|---|---|---|
| Set $V_T$ (ml/kg PBW) | 6 | 7.5 | 9 | 6 | 7.5 | 9 |
| Breathing variables | | | | | | |
| $V_T$e (ml) | 452 (103) | 493 (90)* | 570 (92)*† | 477 (91) | 520 (81)‡ | 591 (91)‡ |
| $V_T$e (ml/kg PBW) | 7.6 (1.5) | 8.2 (0.8)* | 9.5 (0.6)*† | 8.0 (1.4) | 8.7 (0.9)‡ | 9.8 (0.8)‡ |
| f (1/min) | 26 (6) | 23 (6)* | 20 (5)*† | 24 (6)‡ | 22 (6)‡ | 19 (5) |
| PIP (cm $H_2O$) | 18 (5) | 19 (4) | 23 (5)*† | 16 (4)‡ | 18 (5) | 23 (5) |
| PIP-PEEP (cm $H_2O$) | 11 (5) | 12 (4) | 16 (4)*† | 9 (3)‡ | 11 (5) | 15 (5) |
| Peak $\dot{V}_I$ (Lpm) | 46 (4) | 47 (4)* | 48 (4)* | 46 (10) | 48 (10) | 54 (11)‡ |
| $T_I$ (s) | 0.83 (0.15) | 0.90 (0.17)* | 1.09 (0.18)*† | 0.84 (0.16) | 0.96 (0.19)‡ | 1.14 (0.20)‡ |
| Dyssynchronies | | | | | | |
| IT (%) | 0 (0-6) | 0 (0-3) | 1 (0-2) | 1 (0-1) | 0 (0-2) | 0 (0-2) |
| DT (%) | 1 (0-40) | 0 (0-1)* | 0 (0-0)* | 0 (0-33) | 0 (0-1) | 0 (0-0) |
| SC (%) | 2 (0-34) | 0 (0-9) | 0 (0-1) | 39 (1-59)‡ | 0 (0-36) | 0 (0-1) |
| LC (%) | 0 (0-0) | 0 (0-0) | 0 (0-0) | 0 (0-0) | 0 (0-0) | 0 (0-0) |
| FD (%) | 0 (0-4) | 0 (0-50) | 0 (0-20) | 0 (0-0)‡ | 0 (0-0)‡ | 0 (0-0)‡ |
| SFD (%) | 0 (0-64) | 0 (0-10) | 0 (0-0) | 0 (0-0)‡ | 0 (0-0) | 0 (0-0) |

Data expressed as mean (SD) or median (IQR). Dyssynchronies % are calculated as number of events over number of all ventilator cycles with exception of IT which is calculated as number of events over all ventilator cycles + ineffective triggering events. $V_T$: tidal volume; $V_T$e: measured exhaled tidal volume; f: total respiratory frequency; PIP: peak inspiratory pressure; PEEP: positive end-expiratory pressure; $\dot{V}_I$: inspiratory flow; $T_I$: measured inspiratory time; IT: ineffective triggering; DT: double-triggering; SC: short ventilator cycling-off; LC: long ventilator cycling-off; FD: flow dyssynchrony; SFD: severe flow dyssynchrony. * $p<0.05$ compared with 6 ml/kg; † $p<0.05$ compared with 7.5 ml/kg; ‡ $p<0.05$ compared with volume control mode.

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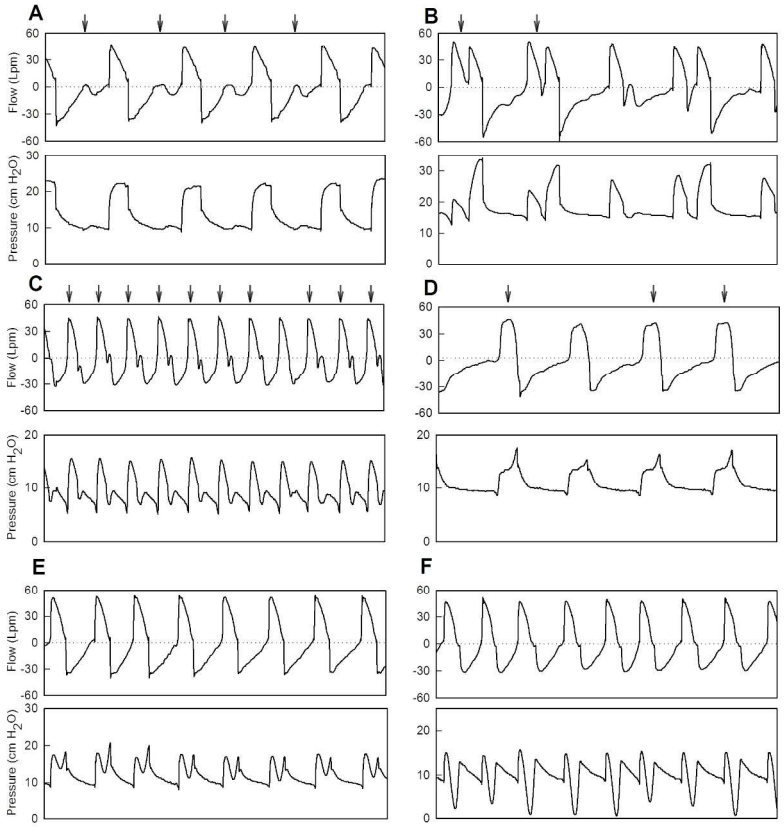


Representative flow-time and airway pressure-time waveforms of patients with the different dyssynchronies assessed in the study. Arrows indicate events or cycles with dyssynchrony except for panels E and F where all cycles show dyssynchrony. A: ineffective triggering: transient decreases in expiratory flow and airway pressure indicate patient efforts to inspire that do not trigger a ventilator cycle; B: double-triggering: 2 ventilator cycles are triggered back to back by the inspiratory effort of the patient reflected by a lower airway pressure in the first cycles of each pair compared to the single triggered cycle; C- short ventilator cycling-off: transient decreases in expiratory flow and airway pressure immediately after the onset of expiration reflect persistent inspiratory efforts after mechanical inflation cycles-off; D: long ventilator cycling-off: sharp increases in airway pressure just before end inspiration reflect persistent positive pressure from the ventilator after cessation of patient inspiratory effort or even initiation of an expiratory effort; E: flow dyssynchrony: the transient decreases in airway pressure during mechanical inflation reflect patient inspiratory efforts clearly un-matched by the flow delivered by the ventilator; F: severe flow dyssynchrony: airway pressure during mechanical inflations reach levels lower than during expiration due to the same

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phenomenon as in E.

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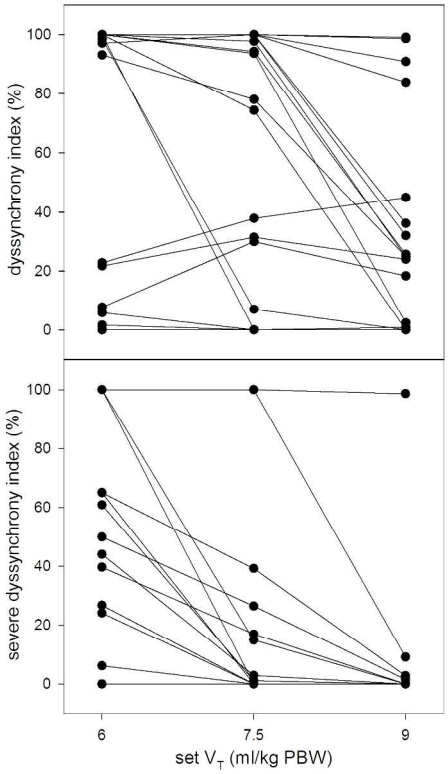


Individual dyssynchrony and severe dyssynchrony indices under volume control mode at different set tidal volumes (VT).

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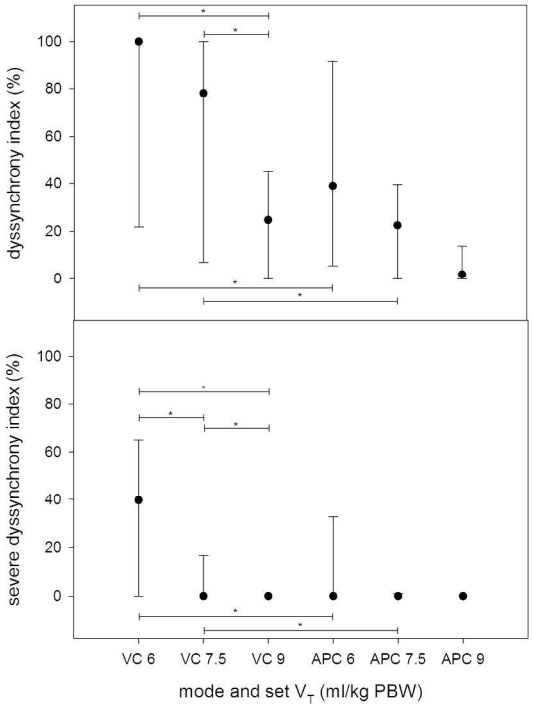


Median and IQR dyssynchrony and severe dyssynchrony indices under volume control (VC) and adaptive pressure control (APC) modes at different set tidal volumes (VT). * indicates p<0.05 for comparisons between set VT sizes on VC mode and between VC and APC modes at the same set VT size.

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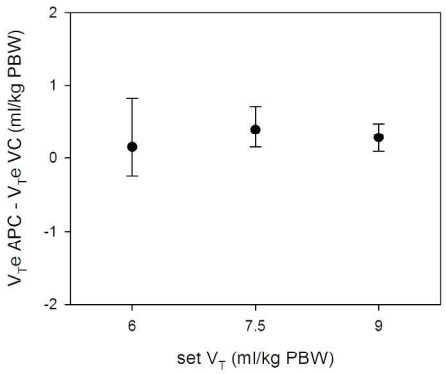


Median and IQR differences in measured exhaled tidal volume (VTe), expressed as ml/kg PBW, between adaptive pressure control (APC) and volume control (VC) mode at each set VT size.

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